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ON THE GENERATION OF CONTINUOUS EMISSION IN COLD STARS

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SUMMARY

This paper attempts to describe the properties of intrastellar matter and to find the mechanism leading to the yield of continuous emission from that matter, which originally was shown by Ambartsumyan to be of nonthermal nature.

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The continuous emission phenomenon discovered by Joy [1], is expressed, as is well known, by a sudden and strong brightness increase of the star (outburst), mainly in the ultraviolet region of the spectrum. This phenomenon, inherent to low-temperature stars of the type G - K - M, is not observed in hot stars. The brightness of the star increases during the outbu st by several, sometimes tens and hundreds of times. A clearly expressed regularity of brightness amplitude increase is observed toward the shortwave side, that is, the stars becomes bluer at flare. In U-rays, for example, according to Haro observations, the amplitude Δm_U reaches 6 - 7^m [2] while the quantity U — B attains up to — 1.5^m [7]. The duration of the outburst or of the process of continuous emission yield is very brief in some instances — from several tens of seconds to several tens of minutes, while in other cases it is measured in months and years. A typical representative of the objects of the first type is the star UV Setus, and of second type — the stars t. Taurus.

At first V. A. Ambartsumyan [3], having subjected the facts linked with the continuous emission phenomenon to a detailed analysis, has shown that it may not have a thermal nature. This author links the phenomenon with the carrying of the intrastellar matter to the outer layers of the star and the liberation there of the intrastellar energy. An attempt will be made in the present paper to describe the properties of this matter and to find the machanism leading to the yield of continuous emission from it.

* O GENERATSII NEPRERYVNOY EMISSII U KHOLODNYKH ZVEZD

Attention should be drawn first of all to an interesting particularity in the distribution of energy in low-temperature stars, consisting in that the number of quanta N_{pg} in the photographic wavelength region constitutes a very small fraction of the total number of infrared quanta N; at the same time the ratio N_{pg} / N drops with the decrease of the effective temperature T of the star (Fig. 1). Still more rapidly drops the relative number of ultraviolet quanta N_U (in the 3000 — 4000 A band) with the decrease of T; as is shown by calculations, the ratio N_U / N constitutes near 3% in type-K5 stars, near 0.2% in the type MO and near 0.02% in the type-M5 stars.

Therefore, in the infrared region of the spectrum the stars of later types have an enormous number of quanta (by comparison with the quanta of the visible band), and that is why it is sufficient to materialize the transition or the transformation of only several percent, and even of fractions of percent of infrared quanta into high-frequency quanta in order to induce the strengthening of the shortwave region of the spectrum by several tens and hundreds of times. A mechanism capable of materializing such a transformation may be indicated: it is the scattering of mean-energy electrons ($\sim 10^6$ ev) on photons, that is, the reverse Compton effect. As is well known, a frequency increase of primary photon takes place in this case according to the correlation

$$\nu \simeq \nu' \left(\frac{E}{mc^2}\right)^2 = \nu' \mu^2, \qquad (1)$$

where ν' is the photon frequency prior to collision with the electron, and ν is that after collision. This correlation is valid with a precision to a well known multiplier of the order of the unity, dependent on the scattering angle.

For that reason we assume that as a result of the outburst electrons appear above the photosphere with energy only slightly greater than its own, that is, of the order of 10^6 ev (we shall designate them as "fast electrons"). These electrons may in particular be separating from the matter being ejected from the interior of stars. The appearance of a sufficiently thick layer of such electrons ($\tau \sim 1$) above the photosphere must lead to a stron g variation of the initial Planck spectrum emerging from that layer of photospherical radiation; there will take place a strong increase of its shortwave part and a weakening of the infrared part. The total number of quanta in the spectrum of the star obviously remains invariable and only some sort of quantum drift takes place from the longwave to the shortwave region of the spectrum; at the same time the additional quantum energy is taken from the energy of fast electrons.

Starting from this consensus, one may set up the problem of determination of emission intensity in the spectrum of the flare $I_\nu(\mu, \tau)$, provided the energy spectrum of electrons μ and the Planck spectrum of photosphere emission* are known. To that effect it is necessary to compose and resolve the transfer equation concomitantly with the condition of radial equilibrium. In case of monochromatic electrons, when the energy of all electrons is identical and equal to μ, this solution has the form

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* $B_\nu(T)$

$$I_\nu(\mu, \tau) = B_\nu(T)\, e^{-\tau} + \frac{\mu^2}{4\pi} \tau e^{-\tau} B_{\nu'}(T), \qquad (2)$$

where τ is the effective optical thickness of the medium over the entire surface of the star on Tomson scattering processes, while B (T) and B (T) are represented by the Planck formula, except that ν' ν/μ^2 should be substituted only in the second case, that is,

$$B_\nu(T) = \frac{2h}{c^2} \frac{\nu^3}{e^{h\nu/kT} - 1}; \quad B_{\nu'}(T) = \frac{2h}{c^2} \frac{(\nu/\mu^2)^3}{e^{(h/kT)(\nu/\mu^2)} - 1}. \qquad (3)$$

The expression (2) is nothing but the theoretical spectrum of the flare.

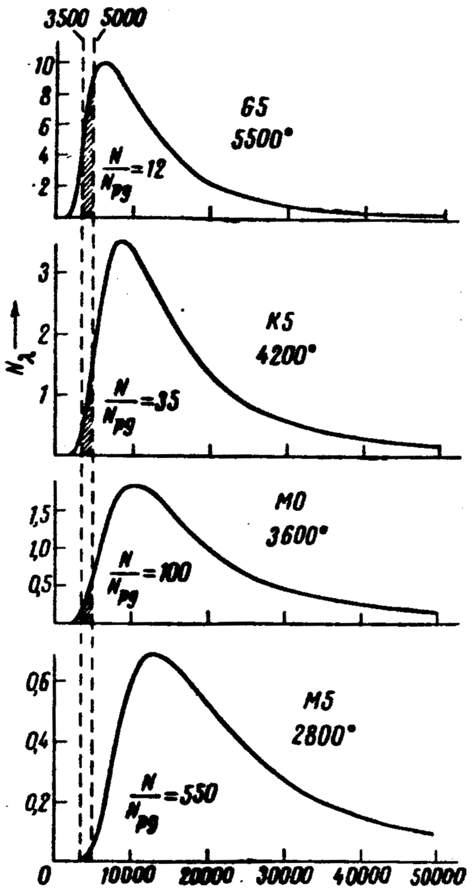


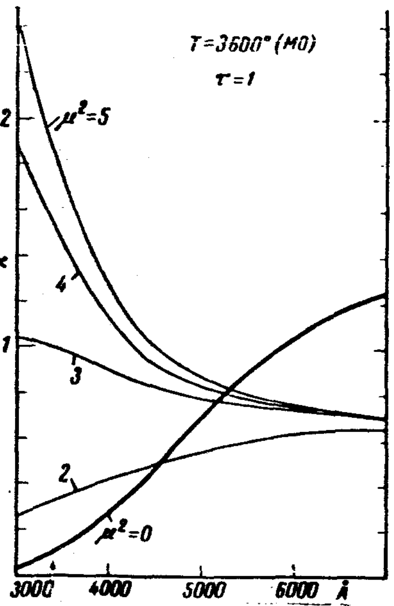
Figure 1 — Distribution of the relative number of quanta in the spectrum of stars of various spectral types.

TABLE 1

μ^2	$B-V$	$U-B$	Δm_V	Δm_B	Δm_U
		$M0$ ($T = 3600°$ K), $\tau = 1$			
0	1,27	+0,45	—	—	—
2	0,82	—0,47	—0,2	0,0	1,0
3	0,44	—1,04	—0,1	0,6	2,1
4	0,32	—1,27	0,0	0,8	2,5
5	0,21	—1,43	—0,1	1,0	2,8
10	0,04	—1,45	—0,3	1,0	2,8
20	0,25	—1,48	—0,6	1,5	2,4
		$M5$ ($T = 2800°$ K), $\tau = 1$			
0	1,80	+1,14	—	—	—
2	0,79	—0,38	0,1	1,0	2,5
3	0,44	—0,87	0,8	2,2	4,2
4	0,20	—1,22	1,0	2,8	5,0
5	0,04	—1,33	1,1	2,9	5,4
10	—0,16	—1,57	1,0	3,0	5,7
20	—0,16	—1,63	0,6	2,5	5,3
		$M6$ ($T = 2500°$ K), $\tau = 1$			
0	2,10	+1,43	—	—	—
2	0,96	—0,25	0,6	1,7	3,5
3	0,44	—0,86	1,4	3,1	5,5
4	0,12	—1,12	1,7	3,7	6,3
5	—0,06	—1,27	1,9	4,0	6,8
10	—0,23	—1,60	1,8	4,2	7,4
20	—0,31	—1,65	1,4	3,9	7,0

As an example we plotted in Figure 2 the curves of relative energy distribution in the spectrum of the flaring star of the type MO (T = 3600°) for various values of μ. The heavy line denotes the normal (Planck) spectrum of the star MO.

The rise of intensity in the shortwave region and its decrease in the longwave region, when fast electrons with either energy appear above the photosphere, is al-



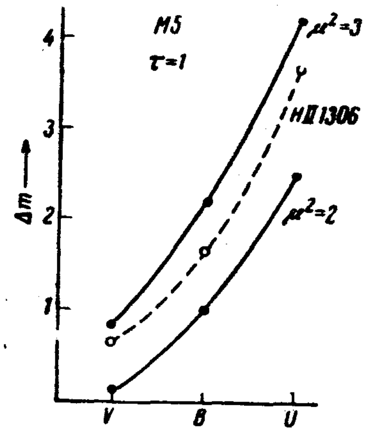


Figure 2 — Theoretical spectrum of the flare of the type — MO star for various values of electron energy μ (thin lines); the heavy line denotes the normal spectrum of the MO star, that is at $\mu^2 = 0$, $\tau = 0$.

Figure 3 — Theoretical dependences of the ultraviolet amplitude of type — M 5 star's flare at $\mu^2 = 2$ and $\mu^2 = 3$ on wavelength; the dashed line indicates the saem dependence found during the observation of the flare of the star H II 1306.

ready visible in that figure. Having plotted such curves for various values of T and μ, we then may compute by standard methods the amplitudes Δm_V, Δm_B and Δm_U, that is, the increase (or decrease) of star brightness in V-, B-, and U- rays by comparison with its normal brightness (when T = 0), and determines also the theoretical color indicators in this system of B - U and U - B. The results of computations for the MO-, M5- and M6- type stars are compiled in Table I, the curves of relative sensitivities in V-, B-, and U-rays being being borrowed from work [4].

We shall conduct certain comparisons with the observations.

1. — The theoretical brightness amplitude reaches 7^m and more in U - rays, as follows from Table I; such amplitudes as indicated above are indeed observed [2].

2. — At the given value of μ, the brightness amplitude increases toward the side of shortwaves (Table I); this conclusion is corroborated by the observation data of [2]. Johnson and Mitchel succeeded in ob-

taining rare electrophotometric readings of brightness variations in V-, B-, U- rays of one flare having occurred with an H II 1306 star. From these curves we determined the amplitudes in V-, B-, and U-rays which are: $\Delta m_V \simeq 0^m,7$, $\Delta m_B \simeq 1^m,7$, $\Delta m_U \simeq 3^m,7$. It was found that such amplitudes may be forming in the case of a flare of an M5 star at $\mu^2 \sim 2 \div 3$, $\tau = 1$ (figure 3).

3. — In normal conditions the color of the star H II 1306 was equal to $B - V = +1^m.35$ and $U - B = +1^m.18$, while at the time of the above flare it became bluer: $B - V = +0^m.50$ and $U - B = -1^m.07$. The color indicators theoretically close to this may be obtained with a flare of type — M5 star, when $\mu^2 = 2.8$ and $\tau = 1$, in this case, $B - V = +0^m.50$ and $U - B = -0^m.80$ (see Table I).

4. — In certain cases, the value of $U - B$ may be smaller than -1^m. Thus, for example, for NXM we have $U - B = -1^m.35$ 6 ; and for the star LH 22, it is still less: $U - B$ $-1^m.5$ [7]. This is found to be in accord with the data of Table I; the concensus of infrared quantum transformation admits the formation of the spectrum of the flare with a very great energy excess in U — rays through the values $U - B \sim -1.70^m$.

*** THE END ***

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